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Comparison of physical characteristics between created and natural estuarine marshes in Galveston Bay, Texas

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Abstract

Five natural and ten created *Spartina alterniflora* marshes in the Lower Galveston Bay System were compared to determine if there were significantly different physical characteristics associated with each type of marsh. The saltmarshes were compared on the basis of microhabitats, length-width ratio, area-perimeter ratio, marsh-water edge ratio, total size of *S. alterniflora* plant communities, fetch distances, angle of exposure, orientation, and elevation. All physical measurements, except for elevation, were obtained from photography analyzed with the use of a Geographic Information System with digital image processing capabilities. Differences existed between natural and created marshes. The natural marsh sites in this study were characterized by highly undulant marsh-water edges, island-like *S. alterniflora* plant stands, concave shorelines, and low elevations. Created marshes were characterized by relatively smooth marsh-water edges, an unbroken shoreline morphology, convex to straight shoreline configurations, and elevations on the edge and inner portions of the marsh higher than those of natural marshes. The low elevations of the natural marsh appear to be due to coastal subsidence in the Galveston Bay area along with rising sea level. Reticulated marshes and undulant shorelines appear to be caused by consequent drowning of the natural marshes. High elevations in some of the created marshes are related to erosion of the low elevation marsh or deposition of coarse sediments at the marsh-water edge.

Introduction

The incidence of wetland loss in the coastal regions of the United States has been profound. The most notable loss of coastal wetlands is occurring in the northern Gulf of Mexico (Gagliano et al., 1981; Turner, 1990; Britsch and Dunbar, 1993; Boesch et al., 1994; Turner, 1997) where extensive estuarine marshes support some of the most productive fisheries in the country (Zimmerman et al., 2000). In the Galveston Bay System, coastal wetlands have decreased by 21% (14,205 ha) from the 1950s resource level (White et al., 1993). There are many causes for the Galveston Bay marsh disappearance, but the most serious are subsidence due to groundwater, oil, and gas withdrawal and relative sea-level rise. Marsh losses on the Gulf coast and in the Galveston Bay system are also due to reduced sediment input into the estuaries and land development for transportation, agricultural, industrial, residential, and commercial purposes (Frayer et al., 1983; Dahl and Johnson, 1991; White et al., 1993). Future losses are projected to be significant as sea level rises and the consequent natural transition of upland areas into coastal marshes is obstructed by developed shoreline (Bigford, 1991; Titus, 1991).

In response to these extensive losses, interest has increased in wetland restoration and creation. Research in the late 1970s suggested that certain wetland systems could be created by humans (Kruczynski, 1990). In these early projects, a created or restored wetland was considered a success if the appearance of the plants on the site was similar to a natural marsh (including plant cover, density, and diversity of species composition), regardless of whether the marsh

functioned similarly to natural marshes or persisted over time (Kusler and Kentula, 1990; Streever, 2000). Some scientists doubt that creation and restoration projects can equitably replace the functional value of natural systems because of the complexity and uniqueness of natural wetlands. In addition, the functional value of a wetland system can be difficult to measure. Our study focused on the physical variables that have the potential to affect marsh functions, particularly in the lower intertidal zone dominated by smooth cordgrass (*Spartina alterniflora*). This marsh community is an important contributor to estuarine primary and secondary productivity, and it provides habitat for many estuarine organisms. The relative importance of salt marshes to infauna, epibenthos, and nekton is related to accessibility, elevation, level and duration of tidal flooding, and the amount of marsh-to-water interface (Gosselink, 1984; Browder et al., 1985; Rozas and Reed, 1993; Peterson and Turner, 1994; Zimmerman et al., 2000).

The general goal of our study was to compare physical differences and structural complexities between natural and created coastal salt marshes in the lower Galveston Bay System. Ten created marshes and five natural marshes in the system (Minello and Webb, 1997) were chosen to test the null hypothesis that selected physical attributes for natural marshes were not different than those for created marshes.

Study area

The Galveston Bay Estuarine System is a 1,554-km^2 estuary that consists of four major bays. It is the seventh largest estuary in the United States and the largest in Texas. This study focuses on the lower portion of the Galveston Bay Estuary System including lower Galveston Bay, East Bay, and West Bay (Figure 1), where extensive shoreline marshes are dominated by smooth cordgrass. The tidal amplitude is narrow, ranging from about 23 cm to 54 cm, but the tides are often affected by wind. The climate of Galveston is predominantly marine, with periods of modified continental influence during the colder months, when cold fronts reach the coast. Temperatures below freezing are recorded on an average of only four times a year (see Webb et al. (1978) for full descriptions).

Methods

Physical characteristics of natural and created marshes were determined through the use of a geographic information system (GIS). Vector-based National Wetland Inventory (NWI) maps and raster-based images were integrated in the GIS. Color infrared aerial photographs of each marsh site were taken specifically for this project in October 1990 at scales from 1:5,000 to 1:12,500. Raster images were derived by scanning at 300 dpi and converting images to a pixel resolution of 0.25-m pixels. The GIS software programs selected for this project, AGIS and MAPIX, were developed by Delta Data Systems in Picayune, Mississippi, USA. These programs enable full modeling and processing capabilities and the creation, importation, and integrated processing of geographic data in raster and vector formats. Each image was georeferenced by matching markers that had been placed in each marsh plus additional points that were surveyed with a theodolite from known points recognized on vector digital USGS topographic quadrangle maps in the GIS. Spatial accuracy of measurements in GIS was approximately 0.5 m based on a comparison of ground and image measurements. The entire transplanted area of created marshes was measured as to length, width, and microhabitat type in the GIS program. Four of the five natural marshes were extensive in size, and boundaries had to be arbitrarily established to provide a representative sample of the marshes. However, shoreline lengths were arbitrarily limited to 400 m and inland extent or marsh width was limited to 135 m.

Each wetland area (Table 1 and Figure 1) was delineated by the image processing module contained within AGIS using the hierarchical classification system developed by Cowardin et al. (1979) and further modified by the United States Fish and Wildlife Service's (USFWS) NWI program. Field reconnaissance was used extensively to ensure accuracy of the interpreted wetland habitats within each study site. The term microhabitat was used to describe the areas within a salt marsh that had characteristically different environmental, physical, or chemical influences, such as at the subsystem level (subtidal or intertidal), class level (occurrence and type of vegetation or substrate), and water regime (depth and duration of flooding or saturation). We focused on microhabitats within the 15 salt marsh sites in which the lower intertidal plant community zone was dominated by *S. alterniflora* (habitat classified as E2EM1N). Eleven microhabitats
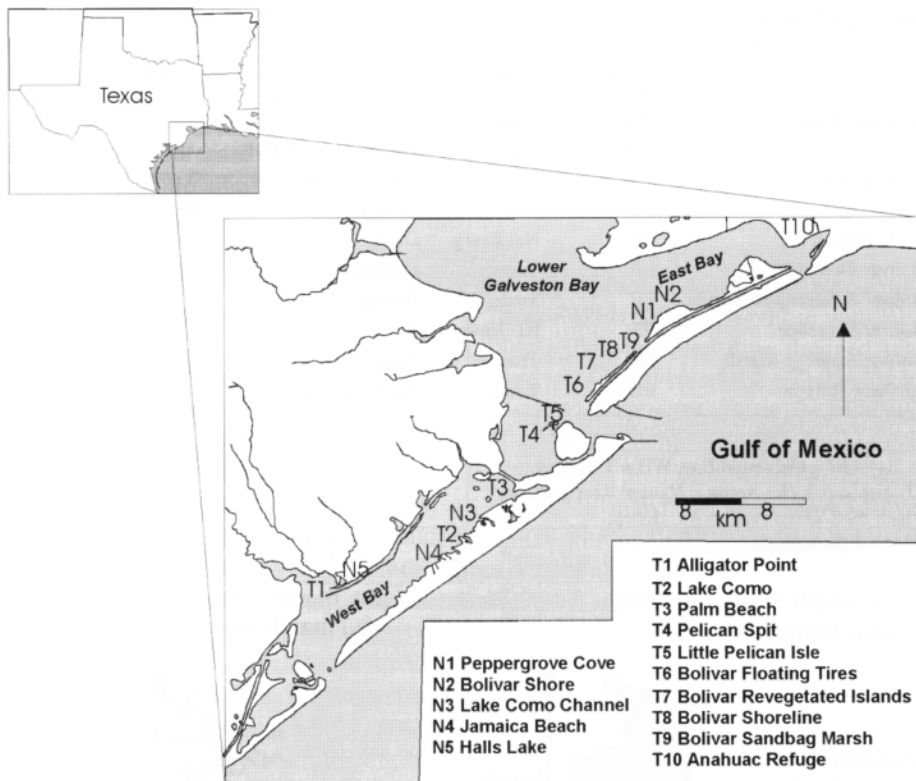
Figure 1. Location of study sites in lower Galveston Bay Ecosystem. Sites N1-N5 are natural marshes and sites T1-T10 are created marshes.

Table 1. Classification system used to define microhabitats within each marsh.

Wetland Classification	NWI Code
Estuarine-Intertidal-Emergent Marsh-Regularly Flooded	E2EM1N
Estuarine-Intertidal-Emergent Marsh-Regularly Flooded – low density	E2EM1N-LD
Estuarine-Intertidal-Unconsolidated Shore/Sand-Irregularly Flooded	E2US2P
Estuarine-Intertidal-Unconsolidated Shore/Sand-Regularly Flooded	E2US2N
Estuarine-Intertidal-Unconsolidated Shore/Mud-Irregularly Flooded	E2US3P
Estuarine-Intertidal-Unconsolidated Shore/Mud-Irregularly Exposed	E2US3M
Estuarine-Intertidal-Unconsolidated Shore/Mud-Regularly Flooded	E2US3N
Estuarine-Intertidal-Emergent Marsh/Persistent-Irregularly Flooded	E2EM1P
Estuarine-Intertidal-Scrub/Shrub-Irregularly Flooded	E2SSP
Estuarine-Subtidal-Unconsolidated Bottom-Subtidal	E1UBL
Estuarine-Subtidal-Reef/Artificial	E1RFr

were recognized (Table 1). Ten created sites with a range in age from young (3 years) to old (15 years) and created with different techniques were chosen for this study (Table 2).

A brief explanation of the physical attributes analyzed in this study follows. *Microhabitat* size for each marsh was determined in square meters using the GIS. Because of the large variability of marsh sizes throughout the study area, microhabitat percentages were determined at each site to standardize the data. The total area of all microhabitats, including upland habitat, was calculated within each defined study site.

Marsh-water edge is the length of marsh, including reticulations, that touched open bay water. The

Table 2. Information concerning transplanted study sites (from Minello and Webb, 1997).

Site	Name	Location[a]	Status[b]	Substrate	Area (km^2)	Time[c]	Age[d]
T1	Alligator Point	WB	Trans.	Dredge	22.9	1983	7
T2	Lake Como	WB	Trans.	Graded Down Upland	0.24	1985	5
T3	Palm Beach	WB	Trans.	Nat Shoreline	0.11	1984	6
T4	Pelican Spit	GB	Trans.	Dredge	4.82	1987	3
T5	Little Pelican Is.	GB	Nat Reveg	Dredge	8.13	1983	7
T6	Bolivar Floating Tires	EB	Trans.	Dredge	0.17	84–85	5
T7	Bolivar Revegetated Islands	EB	Trans.	Dredge	1.26	84–85	5
T8	Bolivar Shoreline	EB	Nat Reveg	Dredge	0.47	83–84	6
T9	Bolivar Sandbag Marsh	EB	Trans.	Dredge	3.00	76–77	13
T10	Anahuac Refuge	EB	Trans.	Nat Shoreline	0.69	1975	15

[a] EB = East Bay, GB = Galveston Bay, WB = West Bay.
[b] Trans. = Transplanted, Nat Reveg = Natural Revegetation.
[c] Year in which marsh construction was done.
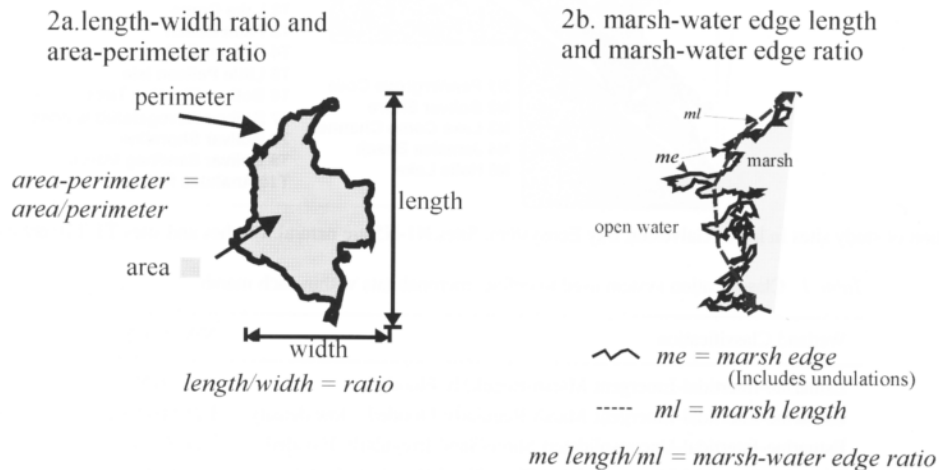[d] At date of aerial photograph.

Figure 2. Diagrams of physical attributes used in the study: a. length-width ratio and area-perimeter ratio, b. marsh-water edge length and marsh-water edge ratio.

length-width ratio is a proportion that was measured for the E2EM1N microhabitat by taking the longest extent of the marsh, the length, and dividing it by the stretch of marsh that was approximately 90 degrees to the length, the width (see Figure 2a.). The *marsh-water edge ratio* was derived by dividing the length of marsh-water edge (including reticulations) by the length of a straight or curved line that followed the outer contour of the marsh (Figure 2b). The *marsh perimeter* is the length of the outer boundary of the marsh. The *area-perimeter ratio* was derived by taking the area of each E2EM1N microhabitat and dividing it by the perimeter of the E2EM1N microhabitat (see Figure 2a).

Fetch measurements were made at three points along the marsh edge of each study site: left extent, middle, and right extent. At each of these points eight azimuths were taken for each site: 0° (North), 45°, 90° (East), 135°, 180° (South), 225°, 270° (West), and 315°. For those angles that were directed into the marsh, a distance of 0 m was recorded.

The *exposure angle* recorded in degrees is determined by shoreline configuration and is a measure of exposure to wave energies (Figure 3). Marsh orientation (Figure 4) describes the direction that the marsh sites face, in degrees. This parameter was taken to determine the direction of wave exposure. In order to determine relative marsh orientation, a straight line was superimposed parallel to the marsh edge. The azi-
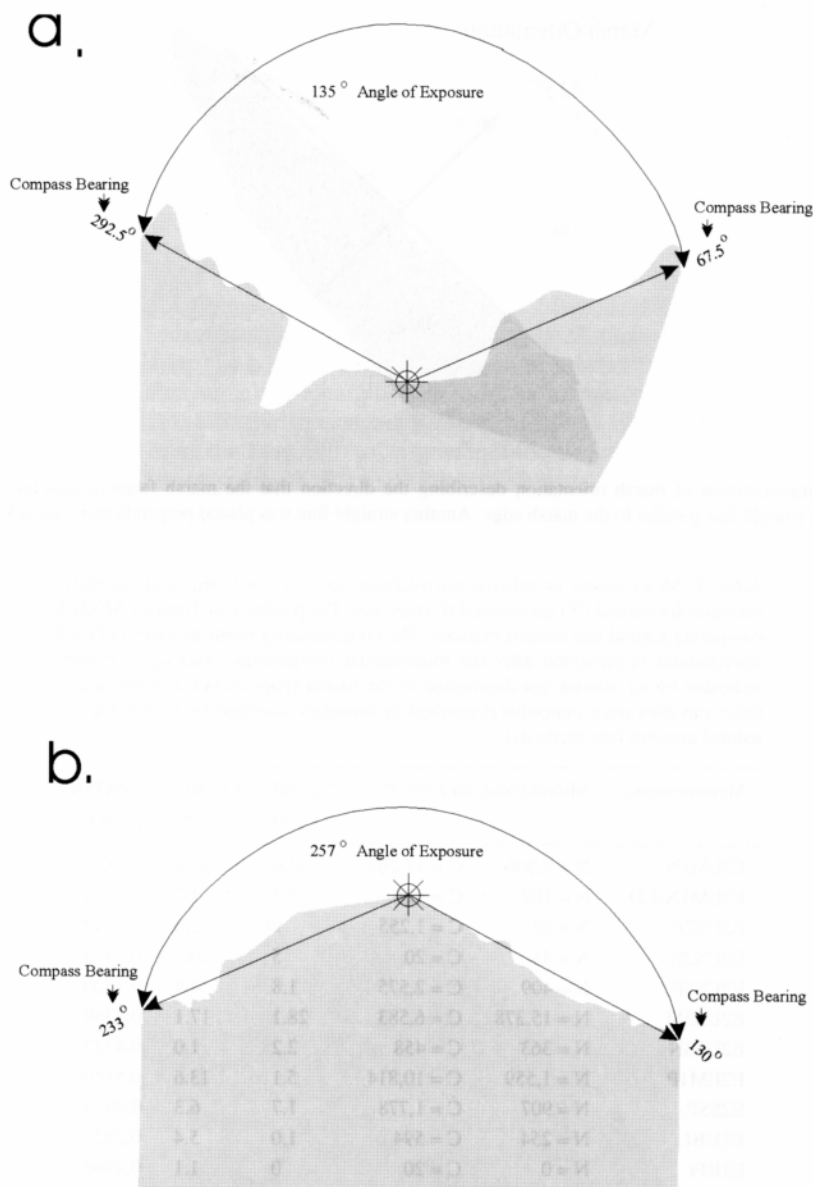
Figure 3. Example of measurement of angle of exposure for each shoreline site. The diagram in 3a shows a marsh shoreline with concave configuration. Figure 3b shows a marsh shoreline with a convex configuration.

muth angle of a line perpendicular to this parallel line was recorded.

Elevations were determined by traversing with an automatic surveying level from a National Geodetic Vertical Datum benchmark elevation to each study site, except sites T7 and T10. At T7 and T10, elevations were based on water levels carried from tide gauges. Within each marsh, elevations were taken on transects at specified distances from the boundaries of sampling zones. In the shallow open water

(nonvegetated), elevations were taken 3, 6, and 9 m bayward of the marsh-water edge. Within the vegetation, elevations were taken at 0, 1, and 2 m distances from the edge of the marsh-water interface (edge habitat) and at 3, 4, and 5 m inland of the marsh-water interface (inner marsh habitat). Approximately 55 elevation measurements were taken for each site. More detailed procedures concerning the methods used to generate the elevation data are described in Delaney and Webb (1995).
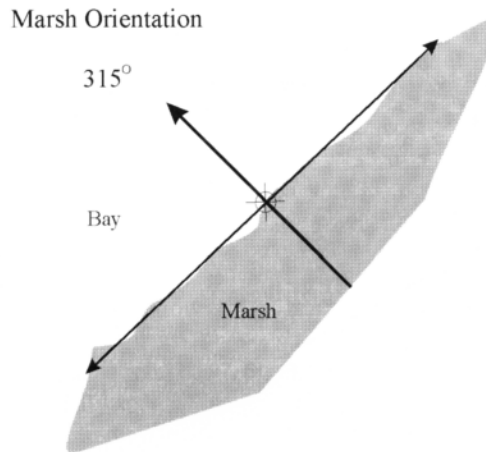
Marsh Orientation

315°

Bay

Marsh

Figure 4. Example of measurement of marsh orientation describing the direction that the marsh faces in degrees. Marsh orientation was determined by placing a straight line parallel to the marsh edge. Another straight line was placed perpendicular to that line and the azimuth was recorded.

Table 3. Mean values of relative microhabitat area (%) and edge and perimeter variables for natural (N) and created (C) marshes. The p-values are from an ANOVA comparing natural and created marshes. The corresponding mean area (m^2) of each microhabitat is presented after the microhabitat designation. Although variables indicated by an asterisk are descriptive of the marsh types included in this study, these variables were somewhat dependent on boundary selection for four of the five natural marshes (see methods).

Measurements	Microhabitat area (m^2)*[1]		Natural (%)	Created (%)	ANOVA p-value
E2EM1N	N = 8,906	C = 17,268	45.0	46.8	0.8839
E2EM1N-LD	N = 107	C = 428	1.2	1.7	0.7350
E2US2P	N = 65	C = 1,255	9	2.6	0.3837
E2US2N	N = 44	C = 20	5	<0.1	0.1525
E2US3P	N = 409	C = 2,575	1.8	4.4	0.7520
E2US3M	N = 15,378	C = 6,583	28.1	17.1	0.3369
E2US3N	N = 363	C = 458	2.2	1.0	0.4722
E2EM1P	N = 1,559	C = 10,814	5.1	13.6	0.5180
E2SSP	N = 907	C = 1,778	1.7	6.3	0.4223
E1UBL	N = 254	C = 594	1.0	5.4	0.2921
E1RFr	N = 0	C = 20	0	1.1	0.4968

Edges and perimeters for E2EM1N (*Spartina alterniflora*) marsh			
MARSH-WATER EDGE LENGTH (m)*	3,052	1,043	0.1712
MARSH-WATER EDGE RATIO (m/m)	10.3	3.3	0.0383
LOWER MARSH PERIMETER (m)*	3,618	1,745	0.2986
AREA-PERIMETER RATIO (m^2/m)*	0.74	6.93	0.0006
LENGTH/WIDTH RATIO (m/m)*	3.1	2.9	0.8977
EXPOSURE ANGLE (degrees)	166	190	0.0353
ORIENTATION (degrees)	234	223	0.8698
ELEVATION-ADJ. BAY BOTTOM (m)	−0.08	−0.03	0.2100[2]
ELEVATION-EDGE MARSH (m)	0.16	0.33	0.0003[2]
ELEVATION-INNER MARSH (m)	0.23	0.47	0.0001[2]

[1] See Table 1 for explanation of habitat types.
[2] p-values are from contrasts that compared created and natural marshes.

The data collected on the marsh systems were analyzed using SAS (SAS Institute Inc., 1985). A one-way ANOVA model was used to compare marsh types (created and natural) for the various dependent variables, after testing for homogeneity of variance with an Fmax test. An arcsine transformation was used on percentage data. For elevations, where there were replicate observations available for each marsh habitat, the one-way ANOVA was used to compare the 15 marshes, and a contrast was used to compare natural and created marshes. Multiple testing of many dependent variables based on a single set of 15 marshes can result in problems of overall significance levels (Rice, 1989; Streever, 2000). Although we considered $p < 0.05$ to be significant, p-values from the ANOVAs are listed in Table 3, and readers can draw their own conclusions regarding statistical significance.

Results

Much of the marsh area examined (about 45%) was categorized into the Estuarine-Intertidal-Emergent Marsh-Regularly Flooded (E2EM1N) microhabitat type. The second most extensive classification was Estuarine-Intertidal-Unconsolidated Shore/Mud-Irregularly Exposed (E2US3M), which made up about 20% of the area in the marshes. There were no significant differences in the relative abundance of any of the microhabitat types measured between the natural and created marshes (Table 3).

Natural and created marshes were significantly different (ANOVA, $p < 0.05$) in their marsh-water edge ratio and area-perimeter ratio. The higher marsh-water edge ratio in natural marshes (mean = 10.34 m per meter) than in created marshes (mean = 3.25 m per meter) indicated that natural marsh areas had highly reticulated or undulant edges while created marshes had relatively straight edges. Similarly, the lower area-perimeter ratio of natural marshes (mean = 0.74 m²/m) when compared to the created marshes (mean = 6.93 m²/m) indicated that created marshes had large expansive areas of vegetation with little undulation along the perimeter while the natural marshes were often collections of fragmented island-like *S. alterniflora* plant stands with highly undulant edges. There were no differences between natural and created marshes in length-width ratios or length of the marsh-water edge. This lack of difference could be an artifact of the subjective establishment of maximum marsh length and width in natural marshes, but it is significant to note

that length-width ratios refer to E2EM1N habitat, and not to the entire marsh.

The created marshes had significantly greater shoreline exposure (mean = 190°) than the natural marshes (mean = 166°). This difference indicates that created marshes had a slightly convex shoreline configuration while the natural marshes possessed a slightly concave shoreline. Fetch distances, however, were not significantly different, and the angle of orientation of natural and created marshes was similar (Table 3).

Natural marsh edges (mean = 0.16m NGVD) had significantly lower elevations (Table 3) than the edges of created marshes (mean = 0.33m); inner marsh elevations (mean = 0.23m) were also lower in the natural marshes compared with the created marshes (mean = 0.47m). The elevation of the nonvegetated bay bottom adjacent to the marshes was not significantly different between natural and created marshes.

Discussion

Natural and created marshes that were examined in this study differed primarily in elevation and *Spartina alterniflora* stand morphology. Differences in area-perimeter ratio, marsh-water edge ratio, and angle of exposure are at least partly related to whether 1) the *Spartina alterniflora* marsh was fragmented (natural) or in large continuous stands (created), or 2) the marsh had undulating shorelines (natural) or convex or straight shorelines with few undulations (created). The lack of differences in fetch and orientation of natural and created marshes indicates that the created marshes were constructed in areas exposed to similar wave conditions.

In natural marshes, the *Spartina alterniflora* plant communities generally occurred in small stands or fragments while the created marshes were generally continuous stands. Natural marshes were both more undulant and reticulated than created marshes. The term undulant describes a sinuous appearance of the interface between the emergent vegetation and the open water of the estuary. The term reticulated is used to describe the interconnected network of channels that occur within many natural marsh habitats. High amounts of reticulation and shoreline undulation affect the amount of interface between marsh vegetation and estuarine water.

The natural marshes studied in the lower Galveston Bay had a mean marsh-water edge ratio more than

three times that of created marshes, indicating that created marshes were established with straight rather than undulant edges. Attempts to establish undulant edges generally were not considered during early marsh construction projects since emphasis was on whether plants could establish on eroding shorelines and dredged material (Woodhouse et al., 1972; Webb et al., 1978; Webb, 1982; Allen et al., 1986; Broome et al., 1988; Streever, 2000). High density of plants with no openings between clones or stands of plants was considered excellent survival and growth. Concern for edge was recognized in later marsh construction projects and edge was added experimentally to two of our created marshes (T1 and T4). Increased edge was shown to increase use of the marsh surface by nekton at T1 (Minello et al., 1994).

The area-perimeter ratio, which was measured for the E2EM1N microhabitats only, enhances the characterization and inferences made regarding the marsh morphology, reticulation, and marsh-water edge differences between natural and created marshes. The lower mean value for natural marshes indicated that natural marshes generally consisted of island-like areas with greatly undulating perimeters. In contrast, created marshes had larger solid stands of vegetation with less undulating perimeters.

Overall elevation of the marsh surface was lower in the natural marshes than in the created marshes. Elevation of coastal marshes can regulate many biological processes such as plant establishment and growth (McKee and Patrick, 1988; Reed and Cahoon, 1992), nutrient cycling (Mendelssohn and McKee, 1988; Nuttle and Hemond, 1988; Childers et al., 1993), abundance and secondary production of estuarine biota (Hummel et al., 1986; Rozas and Reed, 1993; Rozas, 1995), and nekton access (Kneib and Wagner, 1994; McIvor and Rozas, 1996; Connoly, 1999). Previous data from the study marshes showed that densities of some natant macrofauna and macroinfauna were significantly higher in the natural marshes than in the created marshes, and that water depth and flooding duration (i.e., low elevation) were often positively related to animal density (Minello and Webb, 1997).

The relatively high elevations in some created marshes appeared to be caused either by a wave berm or by shoreline erosion. Wave berms are formed by sediment deposition that occurs when high energy waves encounter structures that dissipate their energy. A wave berm was apparent on the edges of T6, T7, T8, and T9 (Webb and Dodd, 1978; Webb et al., 1978).

Deployment of sandbags at T9 (Webb et al., 1978) and a tire breakwater at T6 facilitated a rapid rate of sedimentation at low marsh elevations. The T7 and T8 marshes, located immediately east of T6, also accumulated sand while the edges of the dredge material plume eroded (Allen and Webb, 1993). High marsh surface elevations can also occur through erosion of the marsh edge. For example, the original plantings at T9 were transplanted in 1977 and established as low as 0.0 m NGVD. By 1984, erosion by waves had destroyed the protective sand bag dike in front of the marsh and relocated the marsh edge approximately 25 m inland, leaving a sudden drop off at the marsh-water interface (unpublished data). The elevation of the marsh edge at T9 (0.43 NGVD) in 1991 was one of the highest values measured in our study marshes.

The undulant and reticulated edges and low elevations in our natural marshes appear to be related to marsh deterioration caused by relative sea level rise (due to subsidence, marsh compaction, and actual sea level rise). Historically, the Houston-Galveston area has experienced high rates of subsidence largely due to withdrawal of underground water, oil, and gas. In some areas, up to 3 m of man-induced subsidence occurred between 1906 and 1987, but spatial variability in subsidence rates is high (Gabrysch and Coplin, 1990). Subsidence ultimately leads to marsh disintegration, fragmentation of *Spartina alterniflora* stands, and eventually to marsh replacement by barren shallow sub-aqueous flats or open water (Delaune et al., 1983; McKee and Patrick, 1988; Mendelssohn and McKee, 1988; Reed and Cahoon, 1992; White et al., 1993; Webb et al., 1995). A model developed by Browder et al. (1985) suggests that edge is maximized when disintegrating marshes are approximately 50% land and 50% water. The increased edge associated with marsh disintegration temporarily enhances nektonic access to the marsh surface and supports enhanced secondary production (Faller, 1979; Gosselink, 1984; Rozas and Reed, 1993; Zimmerman et al., 2000).

Created marshes had a greater angle of exposure to waves, which was associated with a more convex shoreline configuration than the natural marshes. Natural marshes had a smaller angle of exposure and a more concave shoreline configuration. The concave shape of the natural marshes appears to be a result of interior marsh deterioration and, on high wave energy shorelines, the formation of berms in front of the marsh edge. The relatively convex morphology in created marshes is probably due to the young age

and the manner in which sediment is deposited. Seven out of ten created marshes in this study were formed from hydraulically dredged material, which formed large plumes that were exposed to waves from many directions.

In summary, we conclude that there were significant differences between natural and created marshes in physical parameters of marsh-water edge ratio, area-perimeter ratio, angle of exposure, and elevation. The natural marsh sites were characterized by highly undulant edges, disintegrating island-type morphology (low area-perimeter ratio values), concave shoreline configurations, and low elevations. These characteristics suggest that the natural marshes are in a state of relatively slow disintegration due to relative sea level rise and that wave berms protect many marshes from erosion. The created sites were characterized by smooth perimeters, a large intact plant community, and convex or straight shoreline configurations. High elevations in some of the created marshes are related to erosion of the lower elevation marsh edge and to deposition of coarse materials at the marsh-water edge. Sea-level rise and subsidence appear to have had limited impacts on created marshes; these marshes were influenced more by erosion associated with their location on high wave energy shorelines. Marshes built in such high-energy environments may reduce erosion and stabilize sediments, but their characteristic high elevations may reduce their value as habitat for estuarine nekton compared with most natural marshes.

Acknowledgements

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